

Evaluation of Computer-Based Volume Measurement and Porous Polyethylene Channel Implants in Reconstruction of Large Orbital Wall Fractures

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PURPOSE. To describe the use of computer-based orbital volume measurement as a predictor of late enophthalmos, and to assess the effectiveness of the MedPor (Porex Surgical Products Group, Newnan, GA) porous polyethylene channel implant to restore orbital volume in repairing large orbital wall fractures.

METHODS. Sixteen patients with unilateral large orbital fractures were included. Computed tomographic (CT) scans were used to obtain computer-based orbital volume measurement to predict the likelihood of late enophthalmos and to assess the change in orbital volume before and after surgery. The effectiveness of a channel implant was evaluated by the orbital volume and postoperative exophthalmometric measurement.

RESULTS. The average time interval between injury and surgery was 17.4 ± 10 days, and the mean follow-up was 9 months. The orbital volume of the injured orbit was significantly increased (mean, 4.22 ± 2.61 cm³) compared with the unaffected orbit before surgery ($t = 3.046$, $P = 0.005$). There was not a significant difference in orbital volume between the two orbits after orbital reconstruction ($t = 0.069$, $P = 0.945$). The orbital volume change after reconstructive surgery was significantly positively correlated with the decrease of enophthalmos ($r = 0.715$, $P = 0.001$; enophthalmos [E] = 0.72; volume increment [V] = 0.06). To resolve 2 mm enophthalmos, more than 2.9 cm³ orbital volume augmentation is recommended for early reconstructive surgery. Postoperative CT scan showed most of the channel implants to be well positioned.

CONCLUSIONS. Computer-based orbital volume measurement from a CT scan is useful in the posttraumatic evaluation of orbital fractures, and it can help predict the degree of late enophthalmos that can be expected. Orbital reconstruction with the MedPor channel implant (Porex Surgical Products Group), when indicated, is recommended, especially for large orbital wall fractures. (*Invest Ophthalmol Vis Sci.* 2006;47:509–513) DOI:10.1167/iovs.05-0816

Large orbital wall fractures pose several potential problems, including diplopia, ocular muscle entrapment, and enophthalmos. Lack of structural support around these frac-

tures makes stable placement of an implant difficult. Surgical intervention is recommended if fracture size portends late enophthalmos or if diplopia and limitation of gaze have not resolved within 2 weeks of injury.^{1,2} Good surgical outcome depends on retrieval of all orbital soft tissue contents, identification of a stable bony platform, removal of unstable bony fragments, and reconstitution of internal orbital bony architecture for appropriate support of the orbital contents.³

Repairing posttraumatic orbital deformities remains a serious challenge.^{4,5} The most feared complication of large and complex orbital wall fracture is enophthalmos, which does not usually present for several weeks to months after trauma because of the associated periorbital or intraorbital edema and hemorrhage.⁶ It is more difficult to correct late enophthalmos than to prevent it by surgical intervention in the early phase.⁷ However, clinical examination immediately after trauma does not provide reliable prognostic information about which injuries are likely to develop enophthalmos and which are not. It is now generally acknowledged that the prolapse of orbital tissues into the sinuses, enlarged orbital volume, atrophy of the orbital fat, and loss of support of orbital walls play a role in the pathogenesis of enophthalmos.^{8,9}

Computed tomography (CT) is recognized as the best imaging technique for evaluating orbital fractures.¹⁰ The coronal CT scan, in particular, demonstrates the extent of the fracture and involvement of orbital soft tissue, allowing objective assessment of fractures. The postoperative CT scan makes it possible to determine whether a satisfactory reduction in orbital volume has been achieved. The degree of enophthalmos is highly correlated with increase in volume of the fractured orbit; according to several literature reports, each cubic centimeter increment in volume causes degrees of enophthalmos ranging from 0.47 mm¹¹ to 0.89 mm¹² and 1.2 mm.¹³

Orbital fractures often undergo surgery soon after injury in an effort to prevent the development of enophthalmos, and many surgical approaches and materials have been used to augment orbital volume and maintain shape. The purpose of our retrospective study was to describe our experience with the use of porous polyethylene channel implants (Medpor Channel surgical implant; Porex Surgical Products Group, Newnan, GA) in large orbital wall fractures and to assess the effectiveness of channel implants on orbital volume restoration. In addition, we describe the use of computer-based volume measurement to predict the degree of enophthalmos in large orbital fractures.

PATIENTS AND METHODS

In this retrospective study, we used a case series design in patients whose orbital wall fractures were reconstructed with porous polyethylene channel implants (Medpor Surgical Implants; Porex Surgical

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FIGURE 1. Preoperative CT scan demonstrating a posterior floor fracture with a prolapse of orbital contents and the methods of volumetric calculation with the Volume program.

Products Group, Newnan, GA) at Ophthalmology Center of Yonsei University College of Medicine, Seoul, Korea. Operations were performed by one surgeon (SYL). The following inclusion criteria were used: unilateral large inferior orbital wall fracture lacking bony support for implant, opposite orbit uninjured, preoperative and postoperative CT scans available, clearly visible reconstructive material on the postoperative images, and patients with follow-up of 6 months or longer and with complete demographic information.

The imaging parameters were 120 kV, 170 mAs, 3-mm section thickness, and continuous slices. The anterior border of the orbital floor was determined as the first CT slice with a visible maxillary sinus and the posterior border as the apex of the orbit.¹³ A measuring tool provided with the software of a computer program (orbital measurement method [Volume program; Yonsei University]) was used for measurement of areas in each coronal CT slice. With the slice thickness of the CT scan known, volumes from areas can be automatically calculated (Fig. 1). Interobserver (correlation = 1) and intraobserver discrepancies (correlation 1) of this computer-based measurement program were low, and measurements were highly reproducible.

The quantitative analysis of orbital changes included the measurement of preoperative and postoperative CT data sets (Fig. 2) concerning orbital volume and enophthalmos measured using a Hertel exophthalmometer. A *t*-test was used to check the volume difference between affected orbit and unaffected orbit before and after surgery. Linear relationships between orbital volume and enophthalmos were

assessed with Pearson's correlation coefficient (*r*). Because of the directional hypotheses, all reported probabilities are one tailed. The statistical significance level was set at $\alpha = 0.05$. All statistical analyses were performed on computer (SPSS 11.5 for Windows; SPSS, Inc., Chicago, IL).

RESULTS

Sixteen patients (11 males and 5 females; average age, 25 years; range, 15–51 years) met the inclusion criteria. Six of the fractures were on the right side, and 10 were on the left. The average time interval between injury and surgery was 17.4 ± 10.0 days (range, 4–45 days). The average follow-up period was 9 months (range, 6–17 months). After surgery, nine (56%) patients had enophthalmos greater than 2 mm. Enophthalmos resolved in 15 (94%) patients after surgery, and 2 mm of enophthalmos remained in one patient. The decrease in enophthalmos after surgery was 1.19 ± 1.05 mm. The improvement of enophthalmos after surgery was statistically significant ($P < 0.01$), as expected.

The orbital volume was measured before surgery. The mean orbital volume of the unaffected orbits was 23.94 ± 3.47 cm³, and the mean volume of the affected orbits was 28.16 ± 4.32 cm³. After surgery, the orbital volume on the surgical side was decreased to 24.08 ± 3.22 cm³; thus, an average decrease was achieved of 4.08 ± 2.45 cm³. The volume and enophthalmos of the unaffected and affected orbits, and the differences between the preoperative and postoperative volumetric differences of the two sides are listed in Table 1. There was a statistically significant difference in orbital volume between the two sides before operation ($t = 3.046$, $P = 0.005$), whereas there was no significant difference after reconstruction ($t = 0.069$, $P = 0.945$; Table 2). The increased preoperative orbital volume and the extent of enophthalmos correlated significantly ($r = 0.658$, $P = 0.003$). The orbital volume change after reconstructive surgery and the resolved enophthalmos also correlated significantly ($r = 0.715$, $P = 0.001$), with the regression formula: $E = 0.72V - 0.06$ (Fig. 3). The expected volume decrease of the fractured orbit associated with 2 mm of enophthalmos correction by surgery was 2.86 cm³, as estimated from linear regression.

Diplopia was resolved in five of six patients within 6 months after surgery. Only one patient had hypertropia, which resolved 1 month after the operation. According to subjective assessment, the position of channel implants in the anterior and middle portion was considered ideal in all cases, except

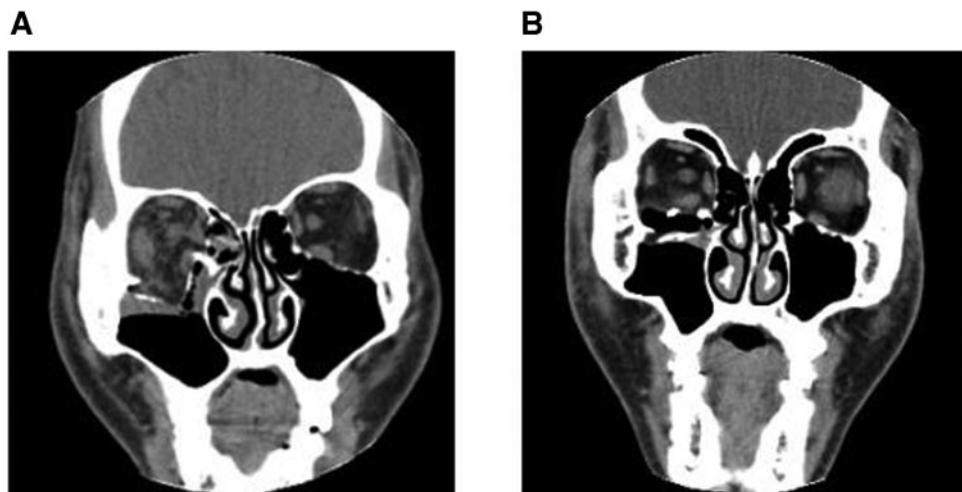


FIGURE 2. CT scan demonstrating a large orbital wall fracture before (A) and after (B) surgery.

TABLE 1. Enophthalmos (mm) and Orbital Volume Changes (cm³) before and after Surgery

Patient	Before				After				Decrease in	
	Affected Orbit	Unaffected Orbit	Differences	En	Affected Orbit	Unaffected Orbit	Differences	En	Orbital Volume	Decrease in En
1	39.09	28.94	10.15	4.5	29.03	29.05	-0.02	0.5	10.06	4
2	25.26	25.12	0.14	0.5	24.46	25.15	-0.69	0	0.80	0.5
3	25.22	21.67	3.55	1.0	22.28	21.88	0.40	0.5	2.94	0.5
4	30.05	29.35	0.7	0	29.67	29.45	0.22	0	0.38	0
5	27.57	24.12	3.45	2.5	23.43	24.08	-0.65	1.0	4.14	1.5
6	26.98	22.39	4.59	3.0	24.43	22.45	1.98	2.0	2.55	1.0
7	32.82	29.12	3.7	0	29.22	29.33	-0.11	0	3.60	0
8	23.07	21.32	1.75	0	20.37	21.50	-1.13	0	2.70	0
9	28.90	22.98	5.92	2.5	24.68	23.01	1.67	1.0	4.22	1.5
10	27.87	21.45	6.42	1.0	22.22	21.44	0.78	1.0	5.65	0
11	29.26	24.32	4.94	1.5	23.88	24.39	-0.51	0	5.38	1.5
12	26.11	23.03	3.08	2.0	23.38	23.08	0.30	0	2.73	2.0
13	25.35	20.68	4.67	2.0	21.02	20.67	0.35	0.5	4.33	1.5
14	33.18	25.07	8.11	2.0	24.89	24.99	-0.10	0	8.29	2.0
15	20.99	16.54	4.45	2.0	17.66	16.56	1.10	0.5	3.33	1.5
16	28.90	26.95	1.95	2.5	24.68	26.95	-2.27	1.0	4.22	1.5
Mean	28.16	23.94	4.22	1.69	24.08	23.99	0.08	0.5	4.08	1.19
SD	4.32	3.47	2.61	1.23	3.22	3.49	1.04	0.6	2.45	1.05

Enophthalmos is expressed in millimeters and orbital volumes and differences in cubic centimeters. En, enophthalmos.

one, in which the CT scan showed poor positioning of the implant in the posterior portion (Fig. 4).

DISCUSSION

The most important component of orbital reconstruction is restoration of the pretrauma volume of orbit. We used a volume measurement program from CT scanning to quantify orbital fractures according to volume change, allowing us to assess the extent and translocation of the fracture, as well as the entrapment and displacement of soft tissue. All these factors affect the decision to choose conservative treatment versus surgical intervention. They also affect decisions regarding design and size of the surgical implant.^{1,2}

Certain orbital fractures continue to pose special challenges. All the cases included in our study were large defects involving more than 50% of the orbital floor. Enophthalmos in such cases is inevitable, but it may be masked in the first days after trauma because of the associated periorbital or intraorbital edema and hemorrhage. We recorded the patients' preoperative enophthalmos when the edema had almost resolved.

Several factors may influence the result of preoperative enophthalmos, including the interval between injury and surgery. This may be one of the reasons that different correlations between orbital volume and enophthalmos have been reported in the literature.¹¹⁻¹³ Recently, early reconstruction has been recommended.¹⁴ The mean time between trauma and surgery in our study was 17.4 days. We found that a decrease of 1 cm³

in volume after reconstructive surgery resulted in a decrease in enophthalmos of 0.66 mm, which was consistent with previous reports on the effect of displacement of orbital tissue on clinical outcome.¹⁵⁻¹⁷

Although the debate continues about which injuries warrant reconstruction, the current trend is to perform reconstructive surgery soon after injury in an attempt to prevent enophthalmos and minimize progressive fibrosis and contraction of the prolapsed tissue.⁷ The orbital volume increment in large fracture cases should be measured before early reconstructive surgery is performed to predict and prevent the possibility of late enophthalmos. The average decrease in orbital volume after single orbital reconstruction in our series was 4.08 ± 2.45 cm³, and the average correction of enophthalmos was 1.19 ± 1.05 mm. To resolve 2 mm of enophthalmos in severe orbital wall fracture cases, more than 2.9 cm³ of orbital volume augmentation is recommended as the goal of reconstructive surgery, according to the formula: $E = 0.72V - 0.06$. Our study demonstrated a distinct difference in volume and enophthalmos correlations that were derived from case series in which reconstructive surgery was performed >4 weeks after trauma.^{11,12}

To correct early or late enophthalmos, the orbital volume must be augmented in a controlled fashion. Several materials have been used for the reconstruction of orbital wall fractures. An ideal implant should have minimal rates of extrusion, exposure, migration, inflammation, and infection. Also, it should be chemically and biologically inert, facilitate tissue ingrowth, and bridge the defects without sagging or

TABLE 2. Comparison of Orbital Volume before and after Surgery in Affected and Unaffected Sides

	Volume of Affected Orbit	Volume of Unaffected Orbit	<i>t</i>	<i>P</i>
Before	28.16 ± 4.32	23.94 ± 3.47	3.046	0.005
After	24.08 ± 3.22	23.99 ± 3.49	0.069	0.945

Data are expressed as mean cubic centimeters ± SD.

changing shape. We used porous, synthetic materials—high-density porous polyethylene channel—in all our cases of large orbital wall fractures that lacked structural support around the defects. In our experience, the Medpor channel implant (Porex Surgical Products Group) provides more optimal reconstruction than other nonabsorbable alloplastic implants. Lack of host fibrovascular integration makes alloplastic implants susceptible to complications, such as infection, implant migration, extrusion, and recurrent hemorrhage.¹⁸ A postoperative CT scan showed most of the Medpor implants to be well positioned, as planned before the surgery. Herniated tissue was released, orbital volume was augmented as expected, and clinical outcome was satisfactory, with only one patient having 2 mm of enophthalmos. The interconnecting, open-pore structure of the Medpor channel implant allows for rapid ingrowth of fibrovascular tissues, and the additional bone ingrowth further stabilizes the implant. Its semirigid structure provides stability when used around the orbit, and yet the malleability of the implant permits easy shaping and contouring.

The implant must be placed exactly to reconfigure the normal orbit anatomy. The lack of implant stability and integration can lead to residual enophthalmos, especially in large defects.¹⁹ We molded the channel implant into the desired shape and secured the implant-plate unit with screws to the designated orbital wall. Once ingrowth occurs and the implant is stabilized, infection, and extrusion is less likely.²⁰

Medpor channel implants can circumvent the dilemmas encountered by the oculoplastic surgeon when reconstructing large orbital wall fractures. Our retrospective study showed it to be particularly useful for a large orbital wall fracture that lacks structural support, for a large orbital volume deficit that requires controlled implant position for volume augmentation, and for a large amount of posterior or medial tissue entrapment.

In conclusion, computer-based orbital volume measurement has an application in quantitative assessment of the extent of fracture and volume of displaced orbital tissue and in predicting enophthalmos. Orbital reconstruction with the Medpor channel implant, when indicated, is recommended, especially for large orbital wall fractures.

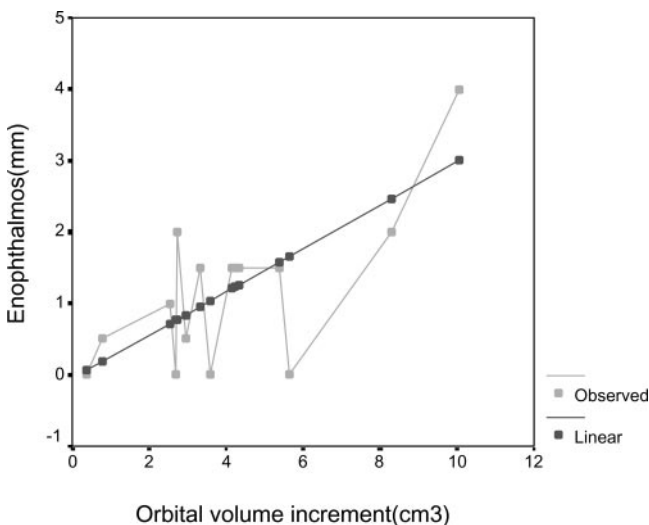


FIGURE 3. Regression line of relationship between augmented orbital volume increment (V) by reconstructive surgery and resolved enophthalmos (E) ($E = 0.72V - 0.06$).



FIGURE 4. CT scan showing unsatisfactory posterior placement of the channel implant.

References

- Harris GJ, Garcia GH, Logani SC, Murphy ML, Sheth BP, Seth AK. Orbital blow-out fractures: correlation of preoperative computed tomography and postoperative ocular motility. *Trans Am Ophthalmol Soc.* 1998;96:329-347.
- Jin HR, Shin SO, Choo MJ, Choi YS. Relationship between the extent of fracture and the degree of enophthalmos in isolated blowout fractures of the medial orbital wall. *J Oral Maxillofac Surg.* 2000;58:617-620.
- Choi JC, Fleming JC, Aitken PA, Shore JW. Porous polyethylene channel implants: a modified porous polyethylene sheet implant designed for repairs of large and complex orbital wall fractures. *Ophthalmic Plast Reconstr Surg.* 1999;15:56-66.
- Hammer B, Prein J. Correction of post-traumatic orbital deformities: operative techniques and review of 26 patients. *J Craniomaxillofac Surg.* 1995;23:81-90.
- Howard G, Osguthorpe JD. Concepts in orbital reconstruction. *Otolaryngol Clin North Am.* 1997;30:541-562.
- Burres SA, Cohn AM, Mathog RH. Repair of orbital blowout fractures with Marlex mesh and Gelfilm. *Laryngoscope.* 1981;91:1881-1886.
- Ellis E 3rd, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus titanium mesh. *J Oral Maxillofac Surg.* 2003;61:442-453.
- Putterman AM. Management of blow out fractures of the orbital floor. III. The conservative approach. *Surv Ophthalmol.* 1991;35:292-298.
- Hawes MJ, Dortzbach RK. Surgery on orbital floor fractures. Influence of time of repair and fracture size. *Ophthalmology.* 1983;90:1066-1070.
- Forbes G, Gehring DG, Gorman CA, Brennan MD, Jackson IT. Volume measurements of normal orbital structures by computed tomographic analysis. *AJR Am J Roentgenol.* 1985;145:149-154.
- Raskin EM, Millman AL, Lubkin V, della Rocca RC, Lisman RD, Maher EA. Prediction of late enophthalmos by volumetric analysis of orbital fractures. *Ophthalmic Plast Reconstr Surg.* 1998;14:19-26.
- Fan X, Li J, Zhu J, Li H, Zhang D. Computer-assisted orbital volume measurement in the surgical correction of late enophthalmos caused by blowout fractures. *Ophthalmic Plast Reconstr Surg.* 2003;19:207-211.
- Ploder O, Klug C, Voracek M, Burggasser G, Czerny C. Evaluation of computer-based area and volume measurement from coronal computed tomography scans in isolated blowout fractures of the orbital floor. *J Oral Maxillofac Surg.* 2002;60:1267-1272.

14. Hosal BM, Beatty RL. Diplopia and enophthalmos after surgical repair of blowout fracture. *Orbit*. 2002;21:27-33.
15. Whitehouse RW, Batterbury M, Jackson A, Noble JL. Prediction of enophthalmos by computed tomography after 'blow out' orbital fracture. *Br J Ophthalmol*. 1994;78:618-620.
16. Manson PN, Grivas A, Rosenbaum A, Vannier M, Zinreich J, Iliff N. Studies on enophthalmos: II. The measurement of orbital injuries and their treatment by quantitative computed tomography. *Plast Reconstr Surg*. 1986;77:203-214.
17. Gilbard SM, Mafee MF, Lagouros PA, Langer BG. Orbital blowout fractures: the prognostic significance of computed tomography. *Ophthalmology*. 1985;92:1523-1528.
18. Jordan DR, St Onge P, Anderson RL, Patrinely JR, Nerad JA. Complications associated with alloplastic implants used in orbital fracture repair. *Ophthalmology*. 1992;99:1600-1608.
19. . Jacono AA, Moskowitz B. Alloplastic implants for orbital wall reconstruction. *Facial Plast Surg*. 2000;16:63-68.
20. Merritt K, Shafer JW, Brown SA. Implant site infection rates with porous and dense materials. *J Biomed Mater Res*. 1979;13:101-108.